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(71) Applicant: **THE ARIZONA BOARD OF REGENTS ON BEHALF OF THE UNIVERSITY OF ARIZONA** [US/US]; The University of Arizona, Tech Transfer Arizona, 220 West Sixth Street, Tucson, Arizona 85701 (US).

(72) Inventors: **ANGEL, Roger P.**; 933 North Cherry Avenue, Room 478, Tucson, Arizona 85721 (US). **STALCUP, JR., Thomas E.**; 1718 East Speedway Boulevard #221, Tucson, Arizona 85719-4515 (US).

(74) Agent: **THOREEN, Alexander C.**; Snell & Wilmer L.L.P., One Arizona Center, 400 East Van Buren Street, Phoenix, Arizona 85004-2202 (US).

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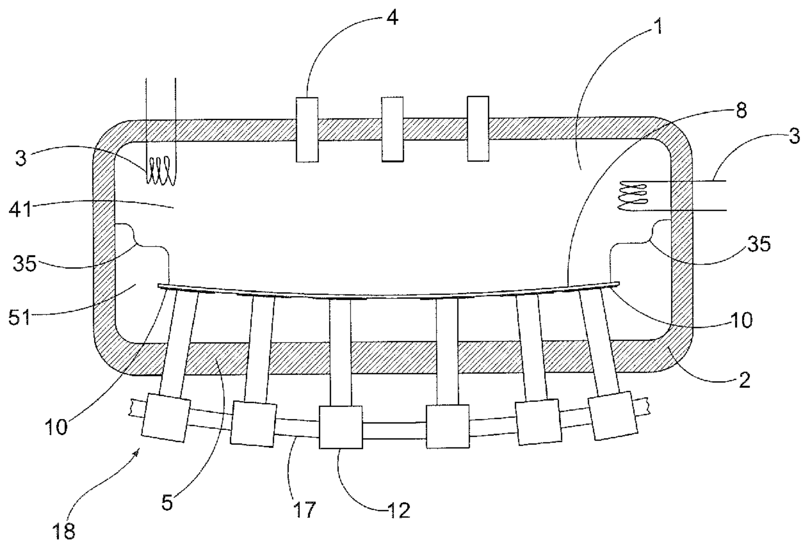

FIG. 1B

(57) Abstract: A system for shaping glass sheets for use in solar collectors may include an oven and an adjustable mold. The adjustable mold may comprise a molding surface located within the oven. The molding surface may be coupled to position actuators located outside of the oven via coupling elements. A glass sheet may be placed in the oven and heated until the glass sheet softens and takes the shape of the molding surface. The molding surface may be adjusted to achieve different shapes for glass sheets.

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GLASS FORMING MOLD OF ADJUSTABLE SHAPE

FIELD

[0001] The present disclosure relates to solar collectors, and more particularly, to molds for creating solar collecting mirrors.

BACKGROUND

[0002] Shaped glass sheets are often used as solar concentrating mirrors. Back-silvered shaped glass mirrors are preferred for this use, as they are proven to maintain high reflectivity in field operation, over many years of exposure. They are also mechanically stable, holding their shape also over many years, with little yielding or fatigue.

[0003] In the past, nearly all curved solar concentrating mirrors have been shaped by rollers after heating and softening. However, this method may be limited in its shape accuracy, typically to > 1.5 mrad rms slope error, and may be limited to shapes that are cylindrical or nearly cylindrical, i.e. curved mostly in one dimension and used to concentrate sunlight to a line focus.

[0004] In the past, most curved glass solar concentrating mirrors forming a point focus were made by sagging into a rigid, dish-shaped, steel mold, for example, in U.S. Patent No. 8,082,755, to Angel and Olbert. High accuracy has been demonstrated by this method (< 1 mrad rms slope error). However, high accuracy shaping may sometimes involve a mold made by machining and refiguring of the machined mold surface to improve fine scale surface accuracy, which can be time-consuming in some applications. If the replica is formed when neither the glass nor the mold is in thermal equilibrium, then the replica shape may deviate from that of the mold. The mold shape may need to be altered to improve larger scale surface errors. Furthermore, large rigid molds may need to be thick to hold their shape accuracy, and as a result, can have high thermal inertia, which makes it difficult to rapidly heat a mold having high thermal inertia without exacerbating the distortion from thermal gradients. As a result, processing cycle times may be slowed.

[0005] In the past, the industry has used solar reflectors curved to very few different shapes, because the manufacturing methods require retooling for different shapes, an expensive and time consuming process. This has inhibited development of new concentrator applications which require unusual shapes, or those that benefit from use of a mosaic of many different replica shapes.

SUMMARY OF THE INVENTION

[0006] A system for forming glass sheets may comprise an oven comprising an insulated perimeter; a molding surface located within an interior of the oven; a plurality of coupling elements in a two-dimensional array configured to adjust a shape of the molding surface, wherein the plurality of coupling elements extend through the insulated perimeter, wherein the shape of the molding surface is configured to define a shape of a glass sheet heated within the oven; and a plurality of position actuators coupled to the plurality of coupling elements, wherein the plurality of position actuators are located exterior of the oven.

[0007] In various embodiments, the molding surface may comprise a plurality of contact segments. The plurality of contact segments may be hexagonal. The system may comprise a positioning plate associated with each contact segment, wherein the positioning plate is movable by position actuators, wherein the positioning plate is located external to the oven, and an insulating block positioned between a contact segment in the plurality of contact segments and its associated positioning plate. A rigid reference structure may be external to the oven, wherein the rigid reference structure supports fixed ends of the position actuators. A plurality of blades may be coupled to the contact segment and its associated positioning plate, wherein the plurality of blades form the coupling element. A first plurality of cooling jets may be configured to direct cooling air to the molding surface, and a second plurality of cooling jets may be configured to direct cooling air to a shaped glass sheet in contact with the molding surface. Each contact segment may comprise a quartz tube having a rounded end, and the rounded ends of the plurality of contact segments may form the molding surface. A cooling jet may be located at least partially within an interior of the contact segment. The molding surface may comprise a metal sheet, wherein the metal sheet comprises a plurality of slits configured to increase a flexibility of the metal sheet.

[0008] A method of shaping a glass sheet may comprise adjusting a two-dimensional array of coupling elements to shape a molding surface for a given mold shape, wherein the coupling elements extend through a perimeter of an oven; positioning a glass sheet above the molding surface; heating the glass sheet; causing the glass sheet to deform and contact the molding surface; and cooling the glass sheet.

[0009] In various embodiments, the method may include measuring a shape of the glass sheet; adjusting at least one of the coupling elements to modify a shape of the molding surface; and shaping a new glass sheet using the molding surface, wherein the shaping the new glass sheet comprises: positioning the new glass sheet above the molding surface; heating the new glass sheet; causing the new glass sheet to deform and contact the molding surface; and cooling the new glass sheet. The molding surface may be coupled to position actuators located exterior to the oven via the coupling elements, wherein the oven is configured to heat the glass sheet. The glass sheet may be cooled with cooling jets, wherein the cooling jets pass through an interior of coupling elements. The coupling elements may be iteratively adjusted until a desired mold shape is achieved. A plurality of replica glass sheets may be shaped without further adjusting the coupling elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The subject matter of the present disclosure is particularly pointed out and distinctly claimed in the concluding portion of the specification. A more complete understanding of the present disclosure, however, may best be obtained by referring to the detailed description and claims when considered in connection with the drawing figures, wherein like numerals denote like elements.

[0011] FIG. 1A illustrates a schematic diagram of an oven and adjustable shape mold with a piece of flat glass prior to shaping, in accordance with various embodiments.

[0012] FIG. 1B illustrates a schematic diagram of an oven and adjustable shape mold after the glass has softened and taken on the shape of the mold, in accordance with various embodiments.

[0013] FIG. 2 illustrates a schematic diagram of an oven and adjustable shape mold with cooling jets, in accordance with various embodiments.

[0014] FIG. 3 illustrates a flow chart showing a mold shape correction cycle, in accordance with various embodiments.

[0015] FIG. 4 illustrates a perspective view of a mold comprising a plurality of molding segments, in accordance with various embodiments.

[0016] FIG. 5 illustrates a cross sectional view showing a detail of the mounting and adjustment of a hexagonal mold segment, in accordance with various embodiments.

[0017] FIG. 6 illustrates a perspective view showing details of the mounting of mold actuator subassemblies, in accordance with various embodiments.

[0018] FIG. 7 illustrates a view of an adjustable mold comprising an array of contact rods, in accordance with various embodiments.

[0019] FIG. 8 illustrates a view of an adjustable mold made with a single piece contact plate, in accordance with various embodiments.

[0020] FIG. 9 illustrates details of an actuator for a continuous mold plate, in accordance with various embodiments.

[0021] FIG. 10 illustrates a plan view showing part of a continuous mold plate with a pattern of cut slits, in accordance with various embodiments.

DETAILED DESCRIPTION

[0022] The detailed description of various embodiments herein makes reference to the accompanying drawings, which show various embodiments by way of illustration. While these various embodiments are described in sufficient detail to enable those skilled in the art to practice the inventions, it should be understood that other embodiments may be realized and that logical, chemical and mechanical changes may be made without departing from the spirit and scope of the inventions. Thus, the detailed description herein is presented for purposes of illustration only and not of limitation. For example, the steps recited in any of the method or process descriptions may be executed in any order and are not necessarily limited to the order presented.

[0023] Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact. Surface shading lines may be used throughout the figures to denote different parts but not necessarily to denote the same or different materials. In some cases, reference coordinates may be specific to each figure.

[0024] The present disclosure relates to a glass forming mold of adjustable shape, used to form glass sheets into a given curved shape. The same mold may be readjusted to form different given shapes if desired. In various embodiments, the adjustable mold parts that form the hot molding surface are constructed with minimum of mass and thermal inertia. Such construction speeds manufacture by minimizing the thermal cycle time needed to soften and shape each sheet of glass, and makes possible tempering of the softened, shaped glass by rapid cooling from below as well as from above. The softened glass may be formed by sagging under the force of gravity alone, or with the addition of air pressure.

[0025] Adjustments of the mold shape may be made with reference to the shape of a test replica made from the mold. If shape measurements of the cooled replica show errors compared to the desired shape, then the mold may be adjusted to reduce these errors, and a new test replica may be formed using the same or modified thermal cycle. This sequence may be iteratively repeated until the replica has the desired shape for a given thermal cycle and actuator settings. Additional replicas may then be formed with the same thermal cycle to have the same shape, and no further adjustment may be needed. If errors develop subsequently, these may be corrected by further mold adjustments.

[0026] In various embodiments, a mold may comprise an array of molding surface elements, individually orientable in tip, tilt and height, and adjusted so as to yield a nearly continuous molding surface. The orienting mechanisms may be external to the heated region of the heating oven. The mechanisms may each include a kinematically mounted support plate, operated by three micrometers. The molding surface elements located within the heated part of the forming oven may be rigidly attached to the external orienting mechanisms by thin blades of steel that pass through the insulated base of the oven.

[0027] Softening of the glass may be accomplished by heating, in various embodiments by radiative heating from above. Thermal radiation at a higher temperature than the glass may be absorbed in part (the longer wavelengths) by the glass. The shorter wavelengths transmitted by the glass may be absorbed by the molding surface elements, which are thus also heated. The thermal inertia of the molding surface elements may be chosen to be comparable to or less than that of the glass to be shaped, so that the time to heat and soften the glass in proximity to the mold is not much longer than the lower limit set by the thermal inertia of the glass alone.

[0028] In various embodiments, the mold may comprise an array of fused quartz tubes, whose tips define the shape of the formed glass. Each tube may pass through the insulated mold, and may be actuated from below by a micrometer screw. To decrease or prevent quilting of the replica caused by local sagging over an individual tube end, cold air may be blown through the tube to freeze the glass locally.

[0029] In various embodiments, the molding surface takes the form of a largely continuous sheet whose shape is adjusted by an array of rods actuated from below. The rods may be positioned approximately perpendicular to the mold surface such that that thermal expansion of the continuous sheet does not cause significant shape distortion.

[0030] In any of these embodiments, the mold may be provided with a multiplicity of air jets to temper the glass by rapid cooling after the shaping. The jets may act to cool both on the upper glass surface from above, and the lower glass surface and the molding surface from below.

[0031] The molds described herein may be utilized to form glass sheets in different shapes, adjustable across their full area. The molds may form glass replicas which will reflect light to a point or line focus or to other optical prescriptions, according to the intended use.

[0032] The molds may provide for correction of the two-dimensional shape of the mold, so that glass shaped by the mold takes on accurately the desired shape, even when this shape is not precisely that of the cold mold, because of distortions in two dimensions caused by thermal gradients in a rapid shaping cycle.

[0033] The shape of the mold may be referenced to a rigid structure whose shape is independent of the heating used to soften the glass for shaping.

[0034] The glass shaping molds may have a minimum of mass and thermal inertia, so that a minimum amount of energy is consumed in heating each mold when a glass sheet is heated to the deformation temperature of the glass for forming against the upper surface of the mold.

[0035] The molds may have low thermal inertia with an open as well as lightweight structure so as to make possible rapid cooling of the glass from below as well as from above, as required for tempering.

[0036] The force used to bring the softened glass against the mold may be either from gravity alone, in a gravity sagging process, or with additional force from air pressure applied to the upper surface of the softened glass.

[0037] Referring FIGs. 1A and 1B, a schematic view of an oven and adjustable mold 18 is illustrated according to various embodiments. FIG. 1A illustrates this system with a glass sheet 8 before shaping, and FIG. 1B illustrates the system after the glass sheet 8 has deformed by gravity sagging or sagging and increased pressure to the shape of the upper surface of the adjustable mold 18. The adjustable mold 18 may be constructed so as to form part of the insulated perimeter 2 of an enclosed volume 1 in which a glass sheet 8 is heated and softened. Heating of the enclosed volume 1 may be by electric elements 3, and the glass temperature may be measured by infrared thermometers 4. A seal 35, which may be flexible, connecting the edge of the glass sheet 8 to the insulated perimeter 2 may be provided to separate the enclosed volume 1 into an upper region 41 above the seal 35, and a lower region 51 below the seal 35. Increased pressure in the upper region 41 may be applied when the glass sheet 8 is softened to accelerate the forming process.

[0038] The adjustable mold 18 may comprise contact segments 10 of the mold that touch the glass sheet 8 after sagging and define its sagged shape. The contact segments 10 may together form a molding surface configured to shape the glass sheet 8. These contact segments 10 are internal to the enclosed volume 1 and are heated along with the glass sheet 8. The adjustable mold 18 may comprise position actuators 12 which are external to the heated volume and remain cold. Coupling elements 11 may link the contact segments 10 to the position actuators 12, allowing adjustment of the mold shape from outside of the oven. The adjustable mold 18 may comprise thermal insulation 5 located between the contact segments 10 and the position actuators 12 that completes the insulated perimeter 2 across the mold while providing for penetration of the coupling elements 11. A rigid mold support plate 17 may support the position actuators 12.

[0039] Referring to FIG. 2, a schematic view of the adjustable mold 18 with air jets 31, 33 is illustrated according to various embodiments. The glass sheet 8 may be tempered by rapid surface cooling. Air jets 31, 33 may be configured to direct relatively cold air across the upper and lower faces of the glass sheet 8. The air may be introduced through the insulated perimeter 2 by ducts 30. The air jets 31 to cool the upper surface may be moved into position after the glass sheet 8 has conformed to the mold. Rapid cooling of the lower surface is possible because the contact segments 10 are lightweight and have low thermal inertia.

[0040] Referring to FIG. 3, a flowchart of a method of adjusting an adjustable mold is illustrated according to various embodiments. The actuators are operated to bring the surface elements of the mold to the approximate desired shape of the molded part. A test sheet may be placed adjacent to a surface of the adjustable mold (step 310). The test sheet may be formed against the adjustable mold according to a prescribed thermal cycle (step 320). After cooling, the test sheet is removed, and its shape may be measured by mechanical or optical metrology (step 330). Any shape errors may be determined (step 340). If the test sheet is not within desired specifications, the adjustable mold shape may be adjusted so as to reduce the errors (step 350), and a new test sheet may be introduced (step 310). The adjustments may be completed by motorized drives operated under computer control. This cycle may be repeated until the processed piece meets the shape specification. The adjustable mold is now ready for manufacture of multiple replicas of the same shape, with limited or no further adjustment (step 360). Metrology measurements may be continued during replica production, so that any long term changes in the replicated shape may be corrected by mold adjustments as needed.

[0041] Referring to FIG. 4, a perspective view of an adjustable mold 18 comprising a plurality of contact segments 10 is illustrated according to various embodiments. The contact segments 10 onto which the glass sheet is formed may be hexagons of an oxidization resistant material such as stainless steel, which may be perforated with holes 101. The shape of a glass sheet when sagged onto the adjustable mold 18 is determined locally by the shape of the surface of the contact segments 10, which is made with the desired shape by, for example, machining or lapping. Globally, the mold shape may be determined by the positioning of the contact segments 10 with respect to each other. The contact segments 10 may be separated by gaps 115. Both the holes 101 and the gaps 115 may be made narrow enough so that the glass does not significantly droop into them during the sag-forming process. FIG. 4 illustrates an adjustable mold 18 formed from 39 contact segments 10, but it will be apparent to those skilled in the art that the number and size of the contact segments 10 can be made as large or as small as desired to obtain the desired mold size and shape. It should be apparent to those familiar with the art that segmentation of the adjustable mold 18 may be made with any number of different shaped elements, the regular array of hexagons as illustrated being simply one example.

[0042] The position and orientation of each contact segment 10 is determined by that of a positioning plate 120. In various embodiments, the positioning plate 120 may be a cold, hexagonal positioning plate. The contact segments 10 and positioning plates 120 may be rigidly connected together by three blades 110. The space between the contact segments 10 and the positioning plates 120 may be filled with an insulating block 21, such as aluminosilicate fiber board, that provides thermal insulation. The contact segments 10 may be coupled to a mold support plate 17 which may be curved to hold the contact segments 10 in a shape approximating the desired shape of the molding surface, as further described herein.

[0043] Referring to FIG. 5 and FIG. 6, FIG. 5 illustrates a perspective view of a mold subassembly 15, and FIG. 6 illustrates a cross-section view of three mold subassemblies 15 according to various embodiments. The unit comprising a contact segment 10, an insulating block 21, a positioning plate 120 and three blades 110 together form a surface subassembly 16, which is integrated with actuators and a mounting plate into a mold subassembly 15. The adjustable mold 18 may be formed by attachment of mold subassemblies 15 in an array to a mold support plate 17 which may be curved to hold the contact segments 10 in a shape approximating the desired shape of the molding surface.

[0044] FIG. 5 shows in detail a complete mold subassembly 15, prior to attachment to the mold support plate 17. The positioning plate 120 which is rigidly connected to the contact segment 10 may be adjusted in tip, tilt and height by three micrometers 128 whose extending micrometer shafts 125 terminate in spherical ball ends 124. The spherical ball ends 124 engage with cone 123, groove 122 or flat 121 elements attached to the positioning plate 120 to form a kinematic mount. In various embodiments, the ball ends engage in three radial grooves 122 cut into the positioning plate 120. The three micrometers 128 are supported via their mounting flanges 126 to a mounting plate 19. The mounting plate 19 provides also the fastening points 131 for each complete subassembly 15 to be attached to the overall mold support plate 17. A tensioning spring 130 is connected between the center of the positioning plate 120 and a mounting plate 19, acting to hold the kinematic mount in compression. The tip, tilt and height of the positioning plate 120 are set by advancing or retracting the three micrometers 128, preferably by means of three drive motors 129. The motors are supported from the mounting plate 19 by brackets 132. In various embodiments, each drive motor 129 or each micrometer shaft 125 may be provided with an encoder which may be read remotely by a control computer. The drive motors 129 may then be operated to make specific correction strokes, as described with reference to step 350 in FIG. 3.

[0045] In operation, when a contact segment 10 is heated it expands, while the positioning plate 120, which remains cold, does not. The blades 110 flex to accommodate this expansion while maintaining centration of the contact segment 10 relative to the positioning plate 120. The blades 110 conduct heat from the contact segment 10 to the positioning plate 120. This heat flow is minimized by keeping the blades thin. Because the blades 110 become heated when the contact segment 10 is hot, they expand, and increase slightly the separation of the positioning plate 120 and the contact segment 10. In order for the positioning of the contact segment 10 to be accurately reproducible from one sag replication to the next, the thermal expansion of the blades 110 may be reproducible, and thus also their average temperature. To minimize changes in thermal coupling, the blades 110 may be insulated by insertion of insulating ceramic fiber 112 in the gaps between the subassemblies, as shown in FIG. 6.

[0046] Heat conducted from the contact segments 10 through the insulating block 21 and through the blades 110 to the support positioning plate 120 may be transferred out of the mold by circulation of coolant behind the positioning plate 120. A plurality of nozzles 133 in the mounting plate 19 may jet cold air onto the positioning plate 120 for this purpose. However, it will be understood by those familiar with the art that other configurations may be used to cool the positioning plate 120, with other coolants such as water, and that these are included within the scope of this invention.

[0047] Referring to FIG. 7, a schematic view of a portion of an adjustable mold 718 comprising an array of contact segments 710 in the form of tubes 711 is illustrated according to various embodiments. The contact segments 710 of the mold that are contacted by the glass sheet 8 after sagging may comprise a two-dimensional array of tubes 711. The contact segments 710 may together form the molding surface where the contact segments 710 contact the glass sheet 8. In various embodiments, the tubes 711 may be hollow and cylindrical. The tubes 711 may comprise a material with low thermal expansion and low thermal conductivity, such as fused quartz. Each tube 711 has a first end 113 and a second end 114. The first ends 113 may be rounded and contact the glass sheet 8 and define its shape. The second ends 114 may be in contact with coupling elements 712. The coupling elements 712 may comprise threaded hollow adjustment tubes, and may be raised and lowered by rotation of the coupling elements 712 within threaded holes 730 in the mold support plate 717. Such rotation may be made manually, or preferably by a motor drive, not shown, operated with an encoder in closed loop servo control. The tubes 711 may be constrained to move along their axis by close fitting holes 16 bored in a cooled mold support plate 717. The tubes 711 also pass through holes 716 in a layer of thermal insulation 705 that extends across the mold support plate 17. In order to ensure that the second ends 114 of the tubes remain in contact with the coupling elements 712, a tension wire may be attached to the inner wall of the tube 711 and pass down through the coupling element 712 to a tensioning spring attached further down in the coupling element 712.

[0048] As part of the sagging process, when the softened glass sheet 8 makes local contact with the first end 113 of the tubes 711, cold air may be blown up through the coupling elements 712 and the tube 711 to freeze the glass sheet 8 locally. This cooling largely prevents further local sagging of the glass sheet 8 around the first end 113 of the tube 711, which would result in a quilted replica surface. The first ends 113 of the tubes 711 may be grooved in order to allow cooling air flow after glass contact.

[0049] In various embodiments, the tubes 711 may be arrayed across the face of the adjustable mold 18 in an array of equilateral triangles. This pattern minimizes the amplitude of quilting. The spacing between the tubes 711 may depend on the thickness of the glass sheet 8 being sagged, and the shape of the glass sheet 8 to be formed by the sagging process. More specifically, if the shape to be formed is deeply curved in two dimensions, hoop strains in the glass sheet 8 may be large, requiring significant stretching or compression of the glass sheet 8. In this case, reduced glass viscosity may be desired, and spacing of the tubes 711 as close as a few times the glass thickness may be desired to keep quilting amplitude to an acceptable level. On the other hand, if only slight bending of initially flat glass sheets is required, by an amount comparable to the elastic bending of the glass sheet under gravity, then the glass may relax enough to take on permanently the mold shape while still being very stiff. In such a case, the tubes 711 may be spaced at distances as much as 10 – 30 times the glass thickness.

[0050] Referring to FIG. 8, the molding surface onto which the glass sheet 8 is to be formed may be a continuous molding sheet 810 whose shape is adjusted from below by a two dimensional array of height control rods 811 (also referred to as coupling elements 811). The first ends 813 of the height control rods 811 may be attached to the molding sheet 810 while the second ends 814 of the rods may be attached to actuator shafts 825 of the position actuators 812, which provide for adjustment of the molding sheet 810. The rod is also preferably made long to minimize geometric errors, and is preferably made of low expansion material to minimize sensitivity of the molding sheet 810 to changes in the thermal environment. The position actuators 12 may be attached to the mold support plate 817 by brackets 127.

[0051] Referring to FIG. 9, a cross-section view of a position actuator 812 and a height control rod 811 is illustrated according to various embodiments. The height control rod 811 may be fitted with a first plug 1131 at the first end 113 and a second plug 1141 at the second end 814. The plugs 1131, 1141 may be held tightly against the ends of the height control rod 811 by an internal tension wire 1120 and a spring 1121, which may be near the cold, second end 814. The first end plug is attached to the molding sheet 810 by a first flexure 1130. The first flexure 1130 may take the form of a thin blade oriented tangential to the center of the molding sheet 810. The second end 114 may be attached to the actuator shaft 825 by a second flexure 1140. The second flexure 1140 also may take the form of a thin blade also oriented tangential to the center of the molding sheet 810. The flexures thus implemented allow for radial thermal expansion of the mold plate on heating – such expansion is accommodated by the rods leaning radially outwards. The geometry is preferably chosen such that when the mold sheet is at glass forming temperature and has expanded in size, the rods 111 are locally perpendicular to the molding sheet 810, so that slight errors in geometry that change the rod angle do not translate to significant errors in the molding surface.

[0052] Referring to FIG. 10, a plan view of a continuous molding sheet 1010 cut so as to reduce shell stiffness, and more easily allow for shape adjustment is illustrated according to various embodiments. The cuts of Y shape 1002 and V shape 1003 may be made by water or plasma jet. The cuts leave the molding sheet 1010 continuous, but effectively divide it into hexagons which are each connected to their neighbors at three nodes 1001, by hairpins. Bending of the hairpins allows for the hexagons to be spread apart or moved closer together, to accommodate hoop strain. The first end flexures in this case may be attached to the molding sheet 1010 at the nodes 1001.

[0053] It will be apparent to those skilled in the art that the three embodiments described above are simply representative examples of the adjustable mold within the scope of this invention, and that other configurations will also fall within its scope.

[0054] Systems, methods and apparatus are provided herein. In the detailed description herein, references to "one embodiment", "an embodiment", "various embodiments", etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

[0055] Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

[0056] Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the inventions. The scope of the inventions is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." Moreover, where a phrase similar to "at least one of A, B, or C" is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C. Different cross-hatching is used throughout the figures to denote different parts but not necessarily to denote the same or different materials.

CLAIMS

What is claimed is:

1. A system for forming glass sheets comprising:

an oven comprising an insulated perimeter;

a molding surface located within an interior of the oven;

a plurality of coupling elements in a two-dimensional array configured to adjust a shape of the molding surface, wherein the plurality of coupling elements extend through the insulated perimeter, and wherein the shape of the molding surface is configured to define a shape of a glass sheet heated within the oven; and

a plurality of position actuators coupled to the plurality of coupling elements, wherein the plurality of position actuators are located exterior of the oven.

2. The system of claim 1, wherein the molding surface comprises a plurality of contact segments.

3. The system of claim 2, wherein the plurality of contact segments are hexagonal.

4. The system of claim 2, further comprising a positioning plate associated with each contact segment, wherein the positioning plate is movable by position actuators, wherein the positioning plate is located external to the oven, and an insulating block positioned between a contact segment in the plurality of contact segments and its associated positioning plate.

5. The system of claim 4, further comprising a rigid reference structure external to the oven, wherein the rigid reference structure supports fixed ends of the position actuators.

6. The system of claim 4, further comprising a plurality of blades coupled to the contact segment and its associated positioning plate, wherein the plurality of blades form the coupling element.

7. The system of claim 1, further comprising a first plurality of cooling jets configured to direct cooling air to the molding surface, and a second plurality of cooling jets configured to direct cooling air to a shaped glass sheet in contact with the molding surface, and wherein

the first cooling jets and the second cooling jets are configured to rapidly cool and strengthen or temper the glass sheet.

8. The system of claim 2, wherein each contact segment comprises a quartz tube having a rounded end, and the rounded ends of the plurality of contact segments form the molding surface.

9. The system of claim 2, further comprising a cooling jet located at least partially within an interior of the contact segment.

10. The system of claim 1, wherein the molding surface comprises a metal sheet, wherein the metal sheet is cut by a plurality of slits configured to increase a flexibility of the metal sheet.

11. A method of shaping a glass sheet comprising:

adjusting a two-dimensional array of coupling elements to shape a molding surface for a given mold shape, wherein the coupling elements extend through a perimeter of an oven;

positioning a glass sheet above the molding surface;

heating the glass sheet;

causing the glass sheet to deform and contact the molding surface; and

cooling the glass sheet.

12. The method of claim 11, further comprising:

measuring a shape of the glass sheet;

adjusting at least one of the coupling elements to modify a shape of the molding surface; and

shaping a new glass sheet using the molding surface, wherein the shaping the new glass sheet comprises:

positioning the new glass sheet above the molding surface;

heating the new glass sheet;

causing the new glass sheet to deform and contact the molding surface; and cooling the new glass sheet.

13. The method of claim 11, wherein the molding surface is coupled to position actuators located exterior to the oven via the coupling elements, wherein the oven is configured to heat the glass sheet.

14. The method of claim 11, further comprising cooling the glass sheet with a cooling jet, wherein the cooling jet passes through an interior of a coupling element.

15. The method of claim 12, further comprising iteratively adjusting the coupling elements until a desired mold shape is achieved.

16. The method of claim 11, further comprising shaping a plurality of replica glass sheets without further adjusting the coupling elements.

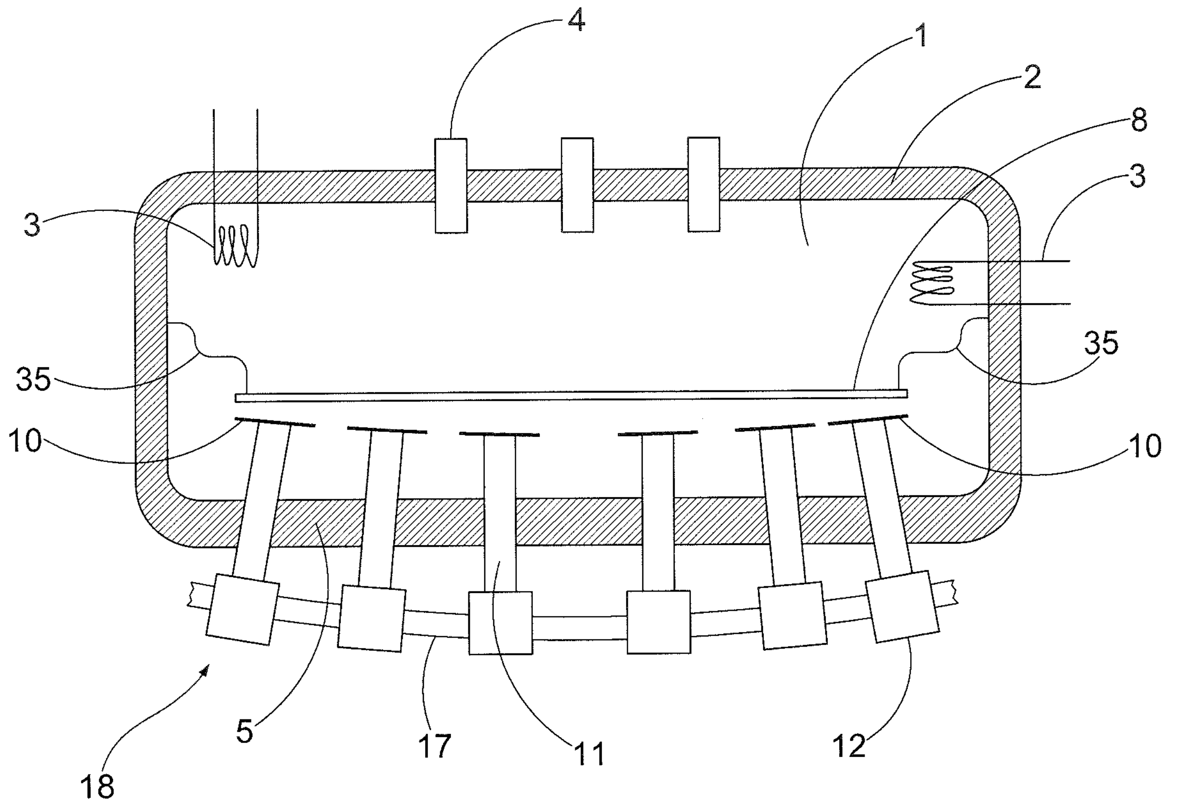

FIG. 1A

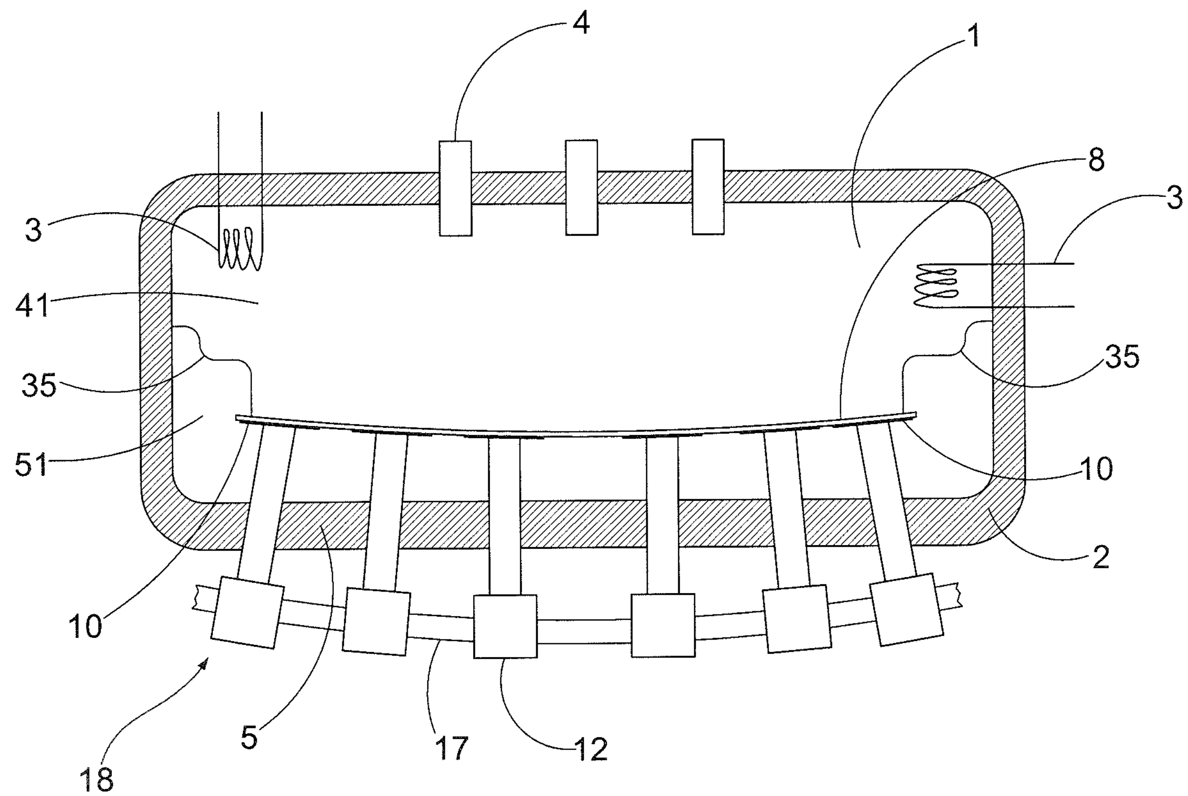

FIG. 1B

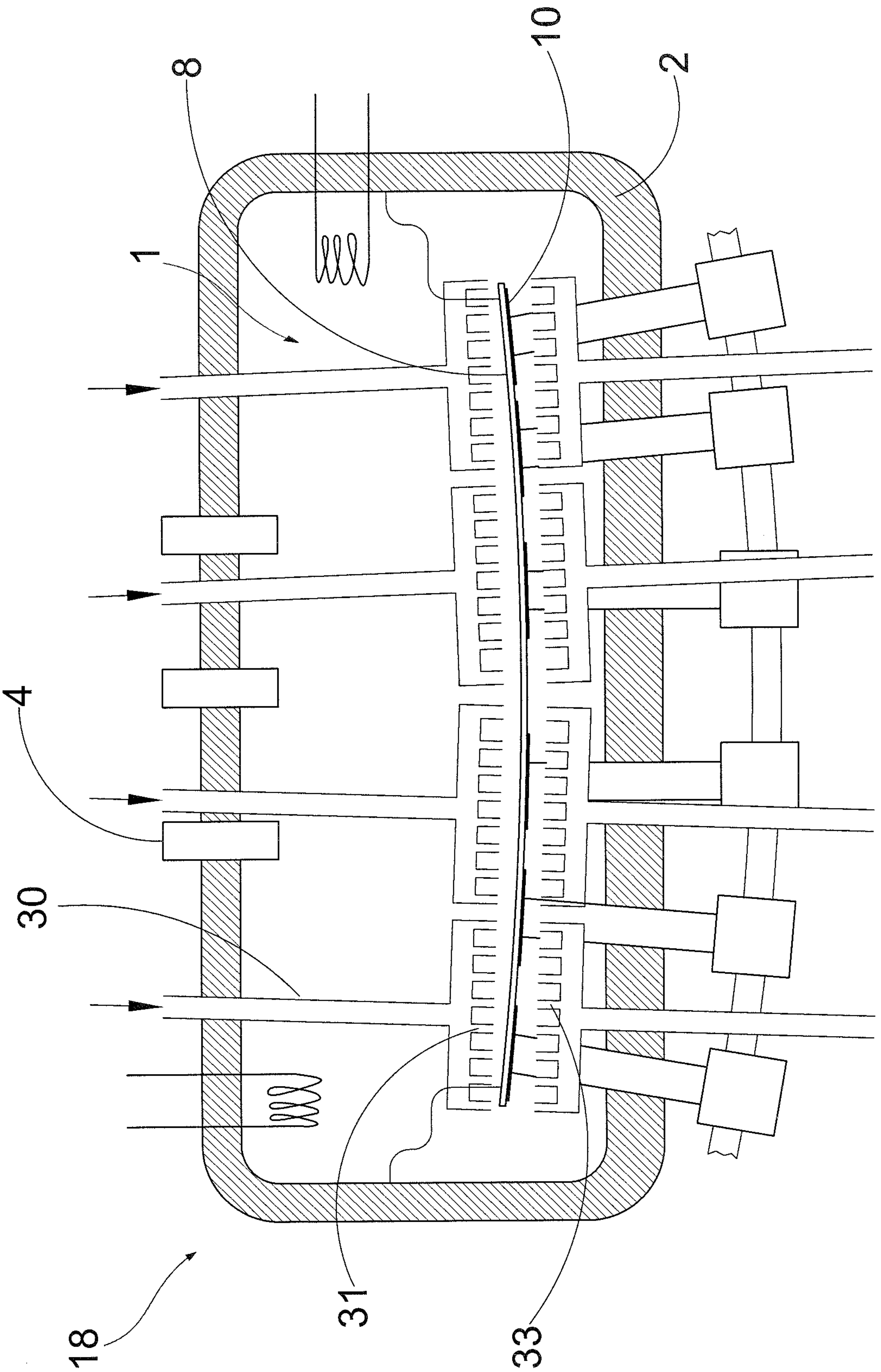

FIG. 2

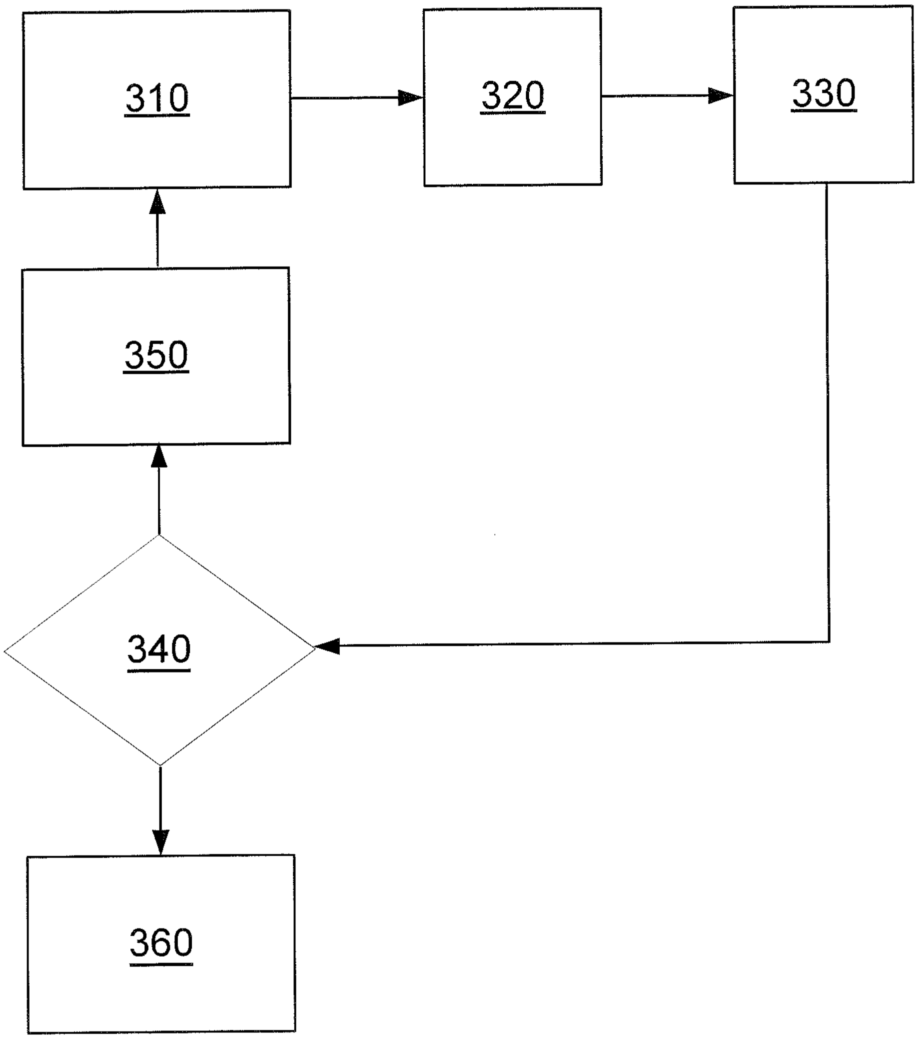

FIG. 3

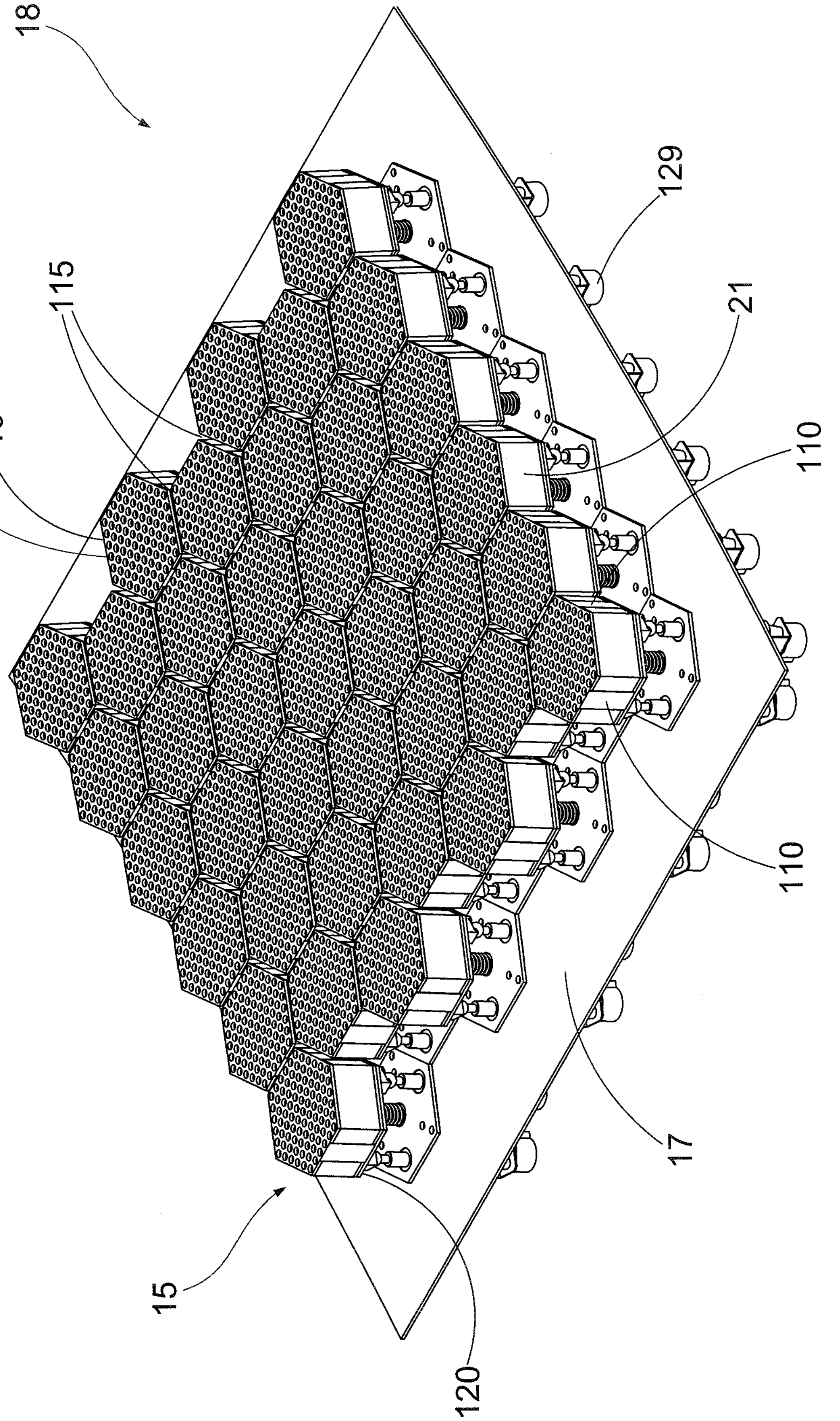

FIG. 4

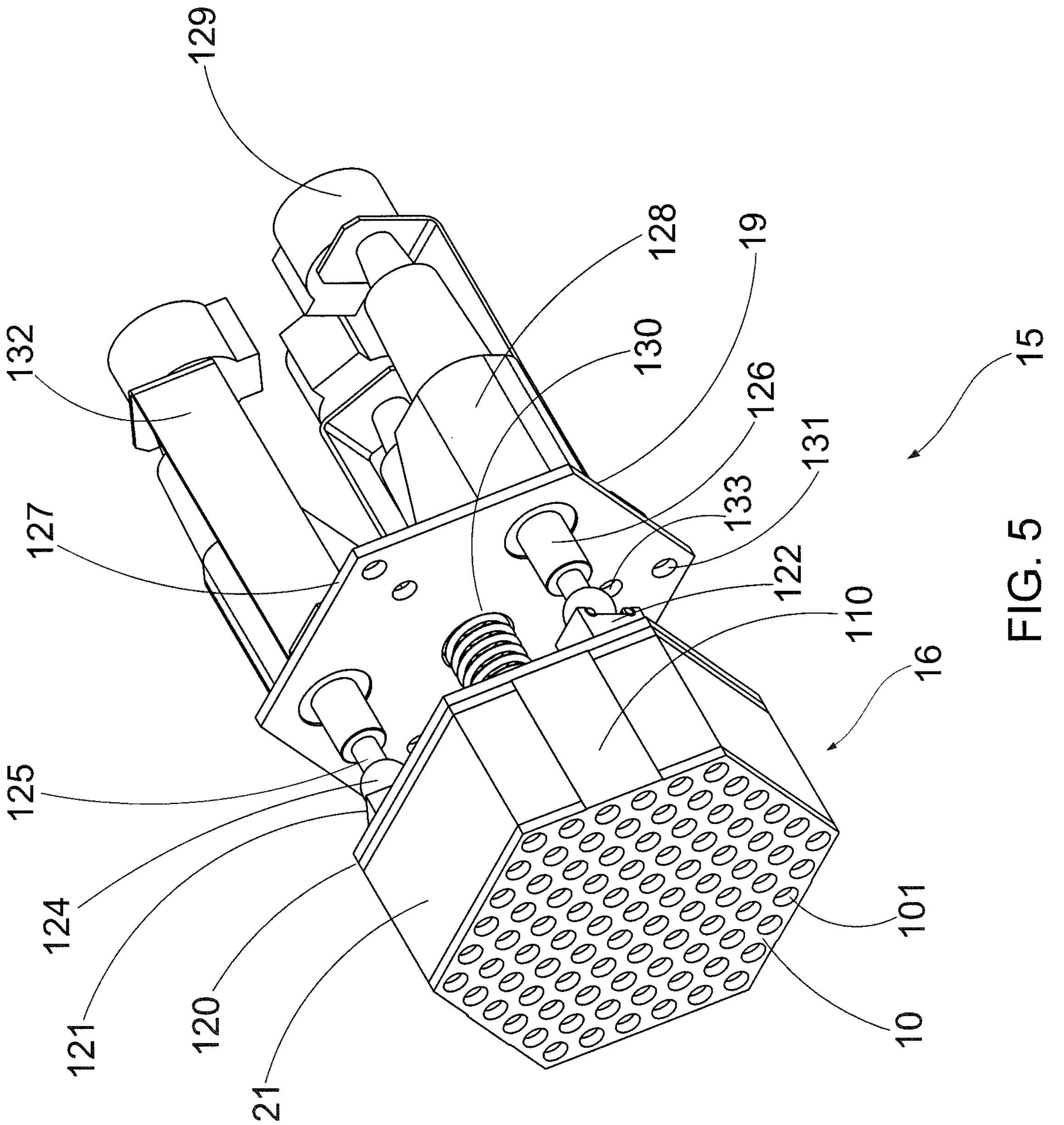
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FIG. 5

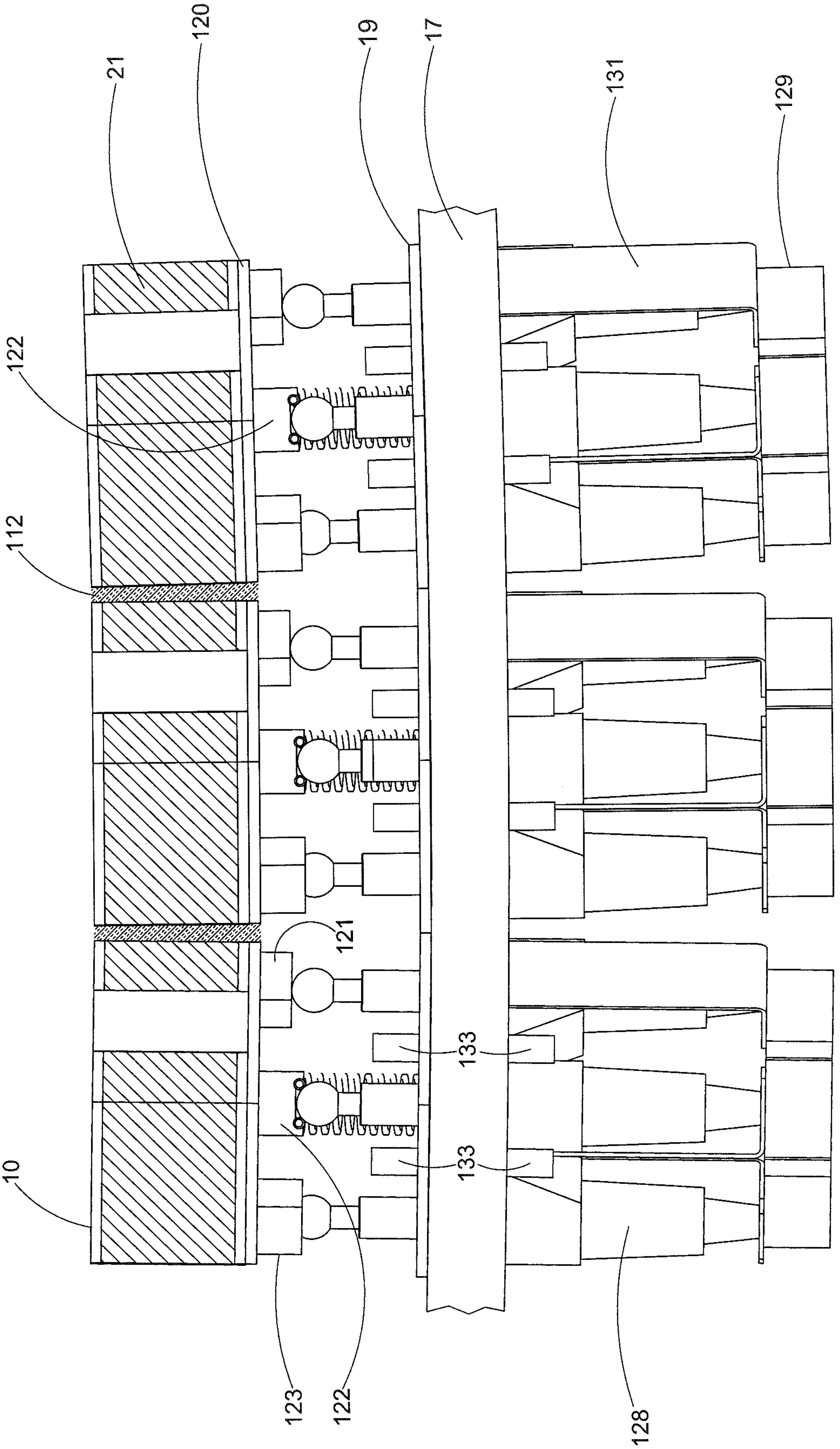

FIG. 6

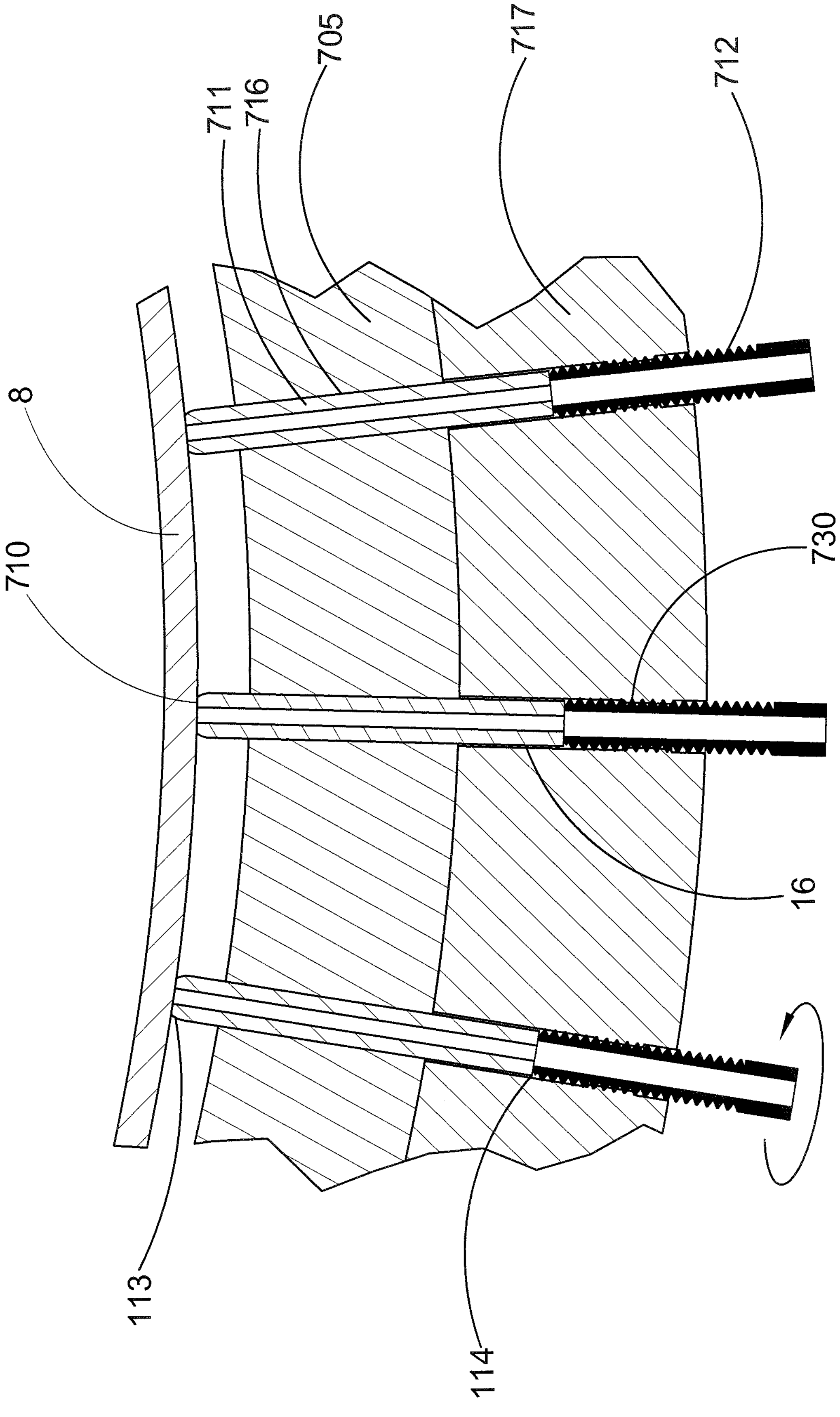

FIG. 7

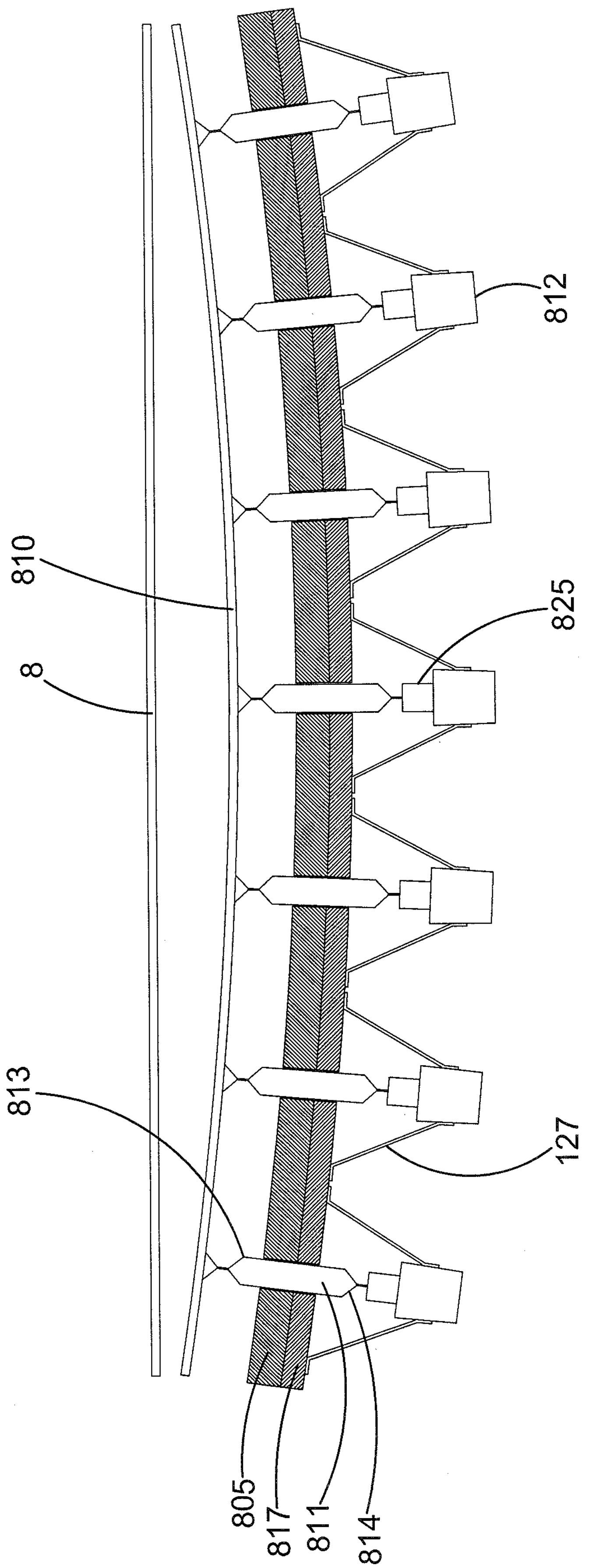

FIG. 8

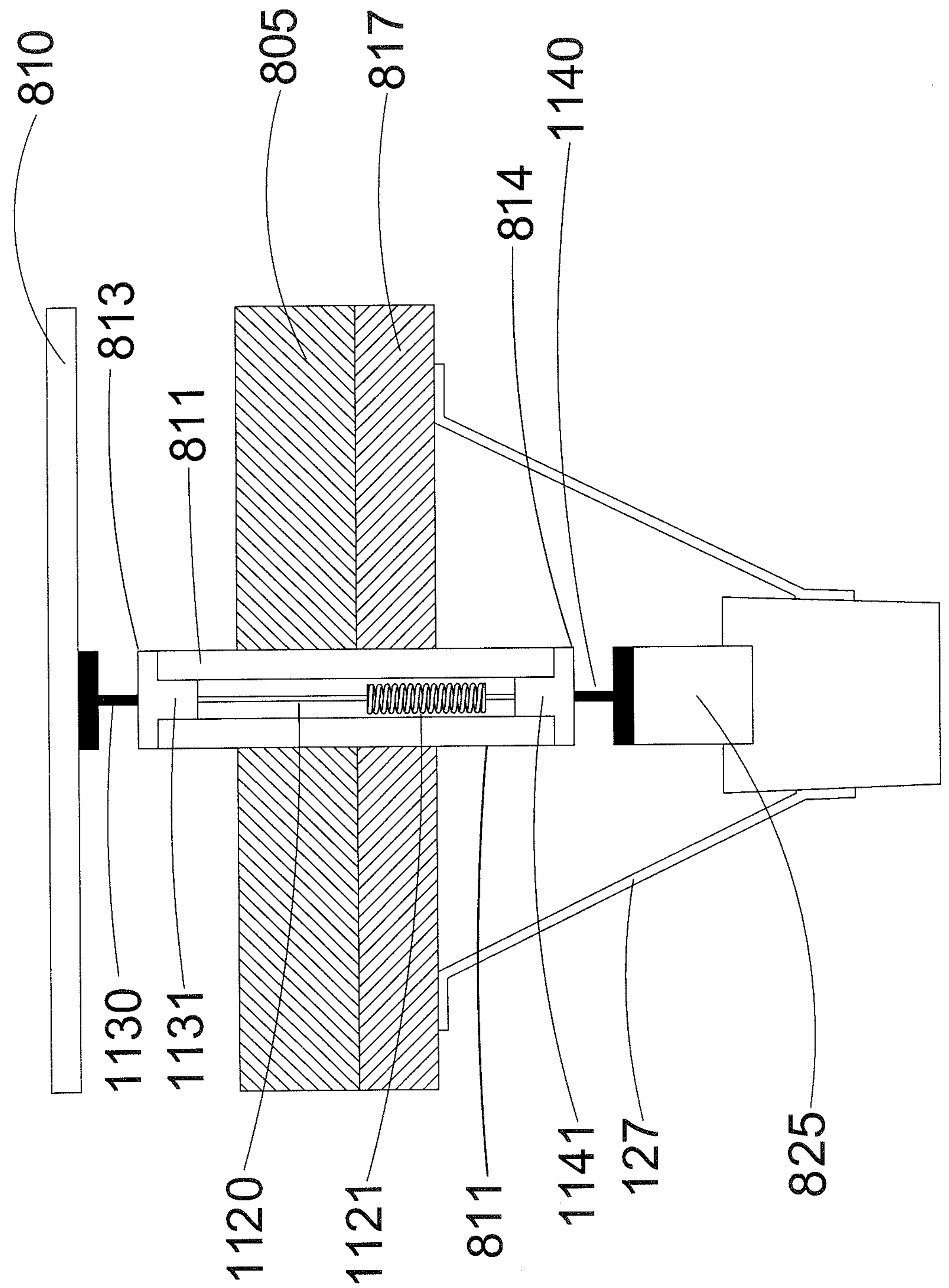
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FIG. 9

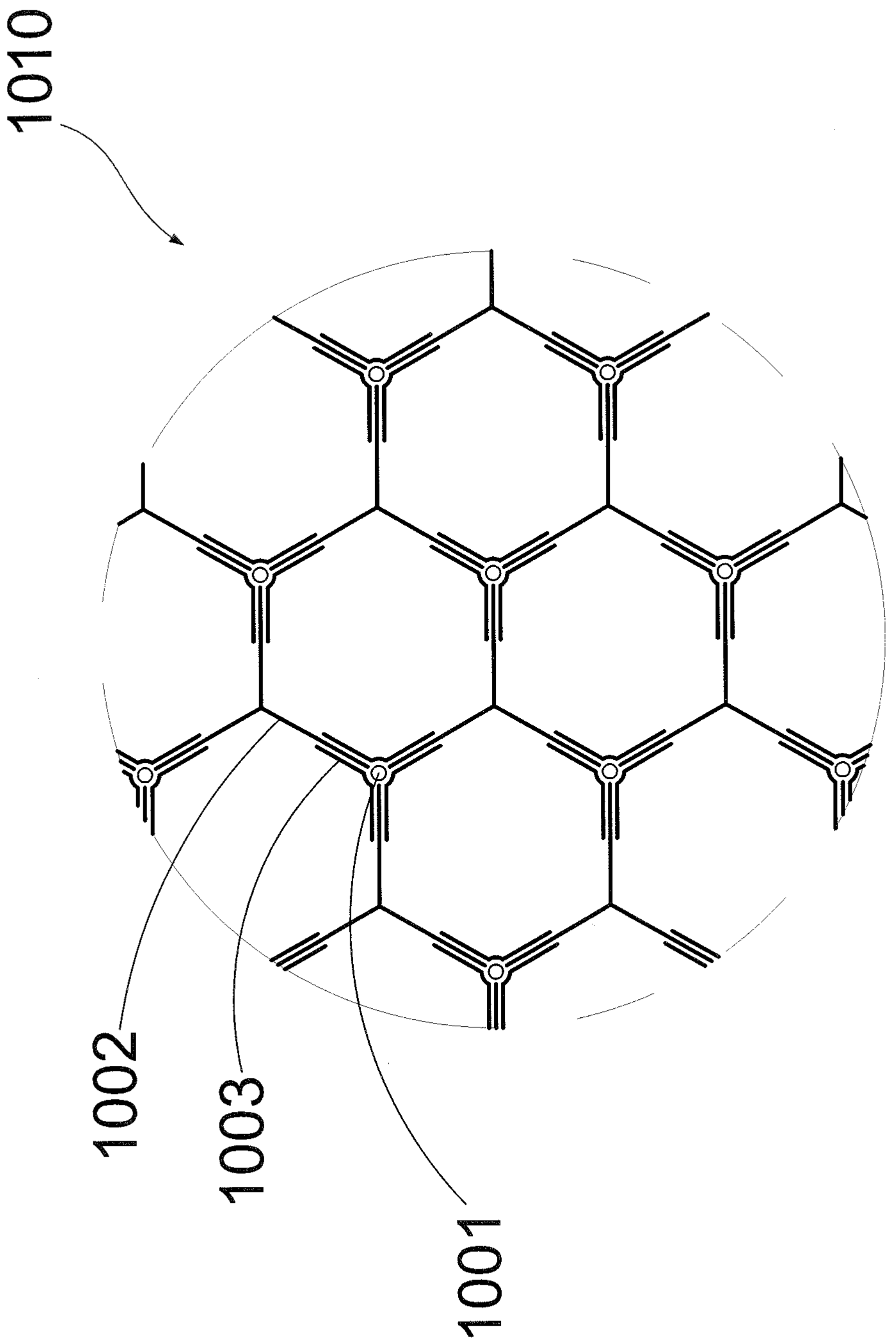

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/20415

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - C03B 23/03, 23/02 (2016.01)
CPC - C03B 23/03, 23/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: C03B 23/03, 23/02 (2016.01)
CPC: C03B 23/03, 23/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, Other Countries (INPADOC), RU, AT, CH, TH, BR, PH), EBSCO, Google/Google Scholar, IP.com
Keywords: glass sheet, adjustable mold, bend

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,697,999 A (REUNAMAKI, PT) December 16, 1997; figures 1-5, 7-8, 11, 14; column 1, lines 50-63; column 3, lines 1-15; column 4, lines 5-25; column 5, lines 25-55; column 5, line 67-column 6, line 3; column 9, lines 48-55; column 10, lines13-58	1-16
Y	JP 2005/206458 A (ASAHI GLASS CO LTD) August 04, 2005; see English translation; abstract, page 7, paragraph 4; page 9, paragraph 4; page 10, paragraph 2; page 11, paragraph 3; page 12, paragraphs 1-3; page 16, paragraph 2; claims 1, 3; figures 1-2, 5	1-16
Y	JPH 0,598,895 A (ISHIKAWAJIMA KENZAI KOGYO KK et al.) April 20, 1993; see English translation; abstract	3
Y	US 7,503,189 B2 (FUKUYAMA, S et al.) March 17, 2009; abstract	8
Y	US 6,566,635 B1 (MATSEN, MR et al.) May 20, 2003; abstract; column 3, lines 10-20	10
Y	US 6,378,339 B1 (ZALESAK, TJ et al.) April 30, 2002; figure 9; column 1, lines 5-10; column 5, lines 45-55	16
A	US 2006/0057847 A1 (YANAGAWA, Y et al.) March 16, 2006; abstract	10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
14 April 2016 (14.04.2016)

Date of mailing of the international search report
03 MAY 2016

Name and mailing address of the ISA/
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450
Facsimile No. 571-273-8300

Authorized officer
Shane Thomas
PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774